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FROM: Francis G. Hinnant, Col, USAF
Associate Director of Acquisition
NPOESS Integrated Program Office
8455 Colesville Rd, Suite 1450
Silver Spring, MD 20910

SUBJECT: Paper approval for: NPOESS VIIRS: Next Generation Polar-orbiting Atmospheric Imager

Enclosed are the required ten (10) copies of the subject papers. This paper will be released at the SPIE (International Society for Optical Engineering) Conference in October of 2002. It was co-authored by Raytheon and NPOESS personnel, and will be presented by employees of Raytheon Santa Barbara Remote Sensing.

The program office has reviewed the information in the attached papers and found it appropriate for public disclosure without change.

Point of contact on this matter is Capt. Ken Speidel, NPOESS IPO/ADA at 301-427-2084 (Ext. 208).

Attachment: Presentation—10 copies

NPOESS VIIRS: Next Generation Polar-orbiting Atmospheric Imager

Carl F. Schueler*[a], John E. Clement*[a], Shawn W. Miller*[a], Peter Kealy** [b], Philip Ardanuy**[b], Stephen A. Cota***[c], Frank DeLuccia*** [c], J. Michael Haas***[c], Stephen Mango***[c], Captain Ken Speidel***[c], Hilmer Swenson***[c]
[a]Raytheon Santa Barbara Remote Sensing (SBRS); [b]Raytheon Information Technology and Scientific Services; [c]NPOESS Integrated Program Office

ABSTRACT

A new era in atmospheric remote sensing will begin with the launch of the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) spacecraft in 2006, and the multiple operational NPOESS launches in sun-synchronous orbital planes (nominally 13:30, 17:30, or 21:30 local equatorial crossing times) starting in 2009. Cloud and atmosphere polar-orbiting environmental satellite data will be profoundly improved in radiometric quality, spectral coverage, and spatial resolution relative to current operational civilian and military polar-orbiting systems. The NPOESS Visible Infrared Imaging Radiometer Suite (VIIRS) will provide Environmental Data Records (EDRs) for day and night atmosphere and cloud operational requirements, as well as sea surface temperature (SST) and many important land EDRs by ground processing of raw data records (RDRs) from the VIIRS sensor. VIIRS will replace three currently operating sensors: the Defense Meteorological Satellite Program (DMSP) Operational Line-scanning System (OLS), the NOAA Polar-orbiting Operational Environmental Satellite (POES) Advanced Very High Resolution Radiometer (AVHRR), and the NASA Earth Observing System (EOS Terra and Aqua) MODerate-resolution Imaging Spectroradiometer (MODIS). This paper describes the VIIRS all-reflective 22-band single-sensor design, following the Critical Design Review (CDR) in Spring 2002[1]. VIIRS provides low noise (driven by ocean color for the reflective visible and near-IR spectral bands and by SST for the emissive mid and long-wave IR spectral bands), excellent calibration and stability (driven by atmospheric aerosol and cloud EDRs, as well as SST), broad spectral coverage, and fine spatial resolution driven by the cloud imagery EDR. In addition to improved radiometric, spectral, and spatial performance, VIIRS features DMSP OLS-like near-constant resolution, global twice-daily coverage in each orbit plane, and direct heritage to proven design innovations from the successful Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and Earth Observing System (Terra and Aqua) MODIS.

Keywords: Environmental Data Record (EDR), Imager, NPOESS, Operational, Radiometer, VIIRS

1. INTRODUCTION

The Visible Infrared Imaging Radiometer Suite (VIIRS) design is based on a set of Environmental Data Record (EDR) requirements defined by the NPOESS Integrated Program Office (IPO) in the VIIRS Sensor Requirements Document (SRD)[1]. The SRD was derived from the combined civil, military, and science communities joint requirements defined in the NPOESS Integrated Operational Requirements Document (IORD)[2]. The Raytheon Santa Barbara Remote Sensing (SBRS) VIIRS design was selected by the IPO in Fall 2000 following a 3-year Phase I "risk reduction" competition to the Preliminary Design Review (PDR) in May 2000. The IPO chose to extend the competition to PDR to reduce development risk for the current Phase II Engineering, Manufacturing and Development (EMD) stage of the program. At the completion of Phase I, independently developed competing suite designs based on the same set of EDR performance requirements were compared by the IPO under a "Best Value" evaluation seeking the best balance of cost, performance, and risk. VIIRS passed the Critical Design Review (CDR) stage of development in Spring 2002, and this paper reports the design status at CDR, updating previous reports[3-6]. The next stage is

* cfschueler@raytheon.com; phone 805 562 7155; fax 805 562 7767; Raytheon Santa Barbara Remote Sensing, 75 Coromar Drive, Goleta CA 93117;**jclement@raytheon.com; phone 805 562 4017

completion in 2003 of a full form, fit, and function Engineering Development Unit (EDU). The EDU allows Raytheon to fully verify the design prior to completion of the first flight model in 2004 for launch in 2006 on the NPOESS Preparatory Project (NPP) spacecraft being developed under contract to NASA by Ball Aerospace and Technologies Corporation (BATC).

The VIIRS SRD defined a number of VIIRS requirements priorities outlined in Table 1, which guided the overall design process from EDR flowdown of sensor specifications to design. Fundamental to these requirements are the EDRs delineated relative to "threshold" and "objective" level performance[3]. Thresholds represent acceptable performance and objectives are usually substantially better performance levels offering additional user benefit. Primary hardware design constraints were dimensions, mass, power consumption, and data rate. The design promises dramatic improvements over the current operational AVHRR and OLS, with proven design heritage from both MODIS and the Sea-viewing Wide Field-of-view Sensor (SeaWiFS).

Table 1: IPO VIIRS Priorities and Raytheon Design Response

IPO Priority	Affordable Excellence Performance
Imagery/SST	Near objective under Target Cost
Cat II Thresholds/Cost	Robust Threshold or Better Overall Performance
Volume	130 x 141 x 85 cm with Passive Cooler
Cat I/IIA Objectives	Most Category IIA EDRs approach Objective
Mass/Power	< 240 W
Cat III Thresholds	All except Net Heat Flux better than threshold
Cat II/IIIB Objectives	Not a design driver
Data Rate	10.5Mbps peak/8.0 Mbps average

Figure 1 shows the single sensor design, and Figure 2 clarifies the functionality. The SRD did not specify a sensor configuration nor did it specify sensor performance requirements, and the term "Suite" in the VIIRS acronym allowed a multiple sensor design approach. Raytheon concluded after evaluation of various design options that a single sensor approach applying the latest proven technologies offered Best Value, yet VIIRS remains a "suite" of hardware and ground data processing algorithms designed together to produce the EDRs. This paper describes VIIRS design trades based on the EDRs using end-to-end system simulation. Sensor performance was predicted using sensor performance models developed by Raytheon SBRS. The simulation allowed Raytheon to conduct extensive trades to select the best balance of sensor performance, cost, design, and risk vs. EDR performance.

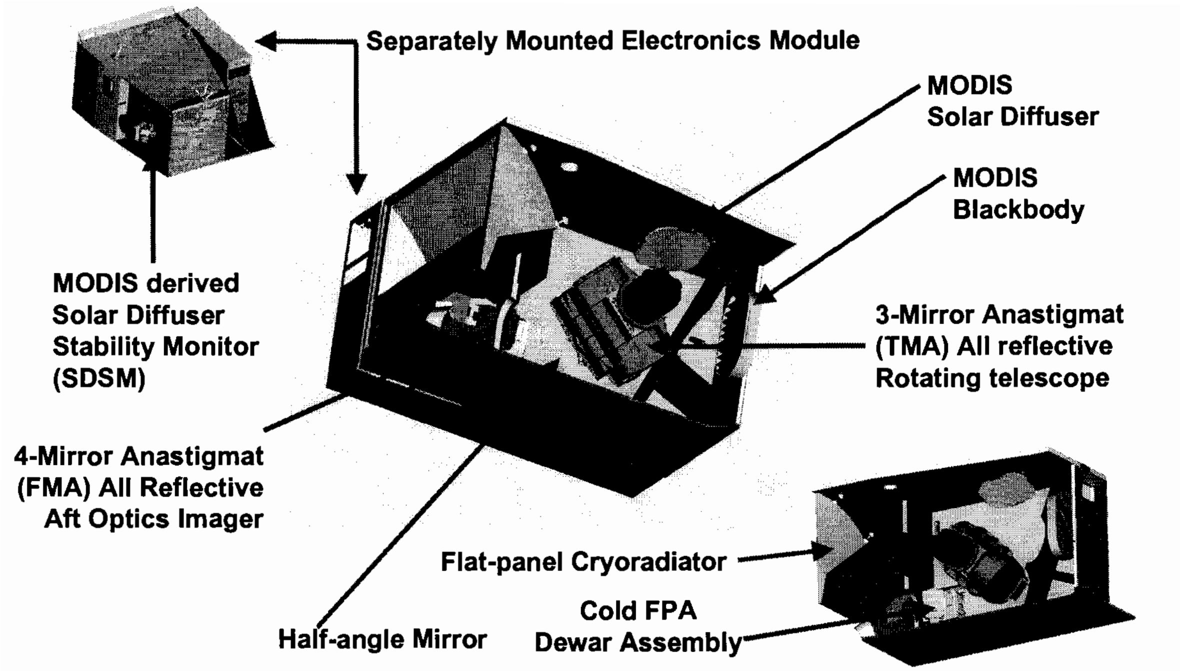

Fig. 1: Single sensor VIIRS design contains substantial flight hardware heritage.

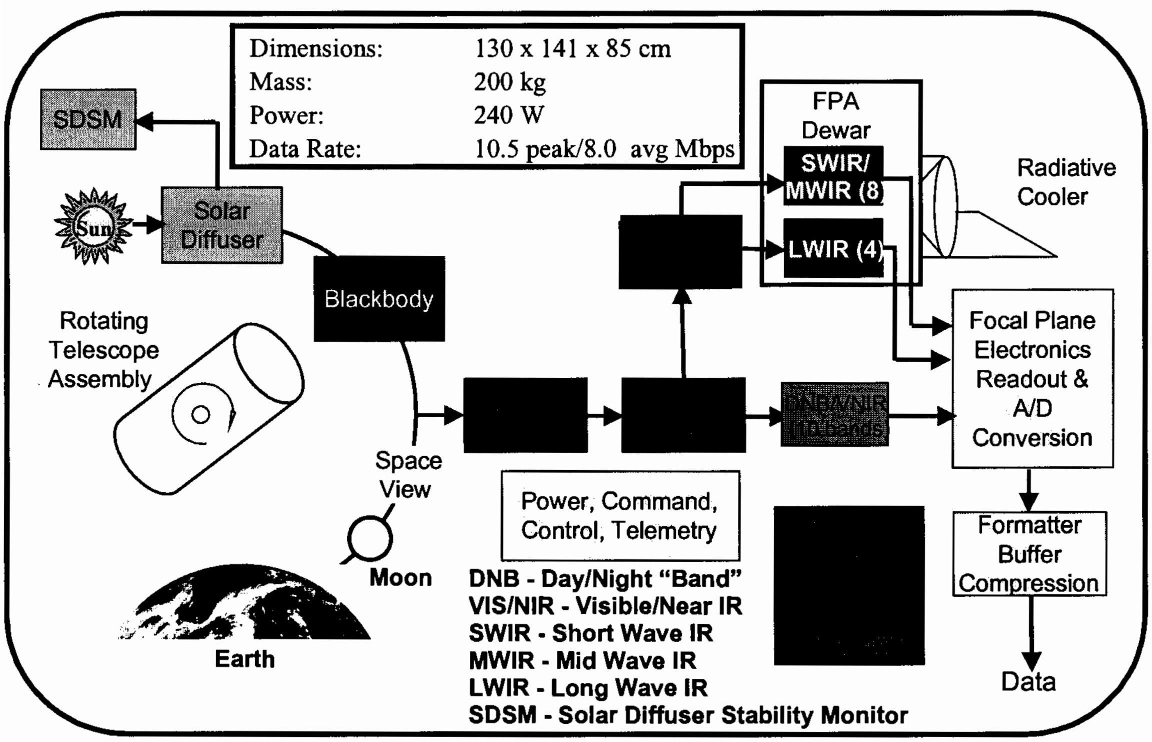

Fig. 2: VIIRS block diagram traces photons from the earth scene or internal calibration mechanisms to the focal plane arrays (FPA) and data output.

2. VIIRS DESIGN TRADEOFFS

Remote sensing design has long depended upon iterative analysis of sensor performance using computer aided design (CAD) tools to balance design based on a data quality specification. The data quality specification has, however, typically been provided by the mission planner in response to geophysical measurement requirements. The translation of geophysical requirements to data specifications has depended upon prior sensor experience, or on simulation of new data capabilities. Optimization tools, such as atmospheric radiative transfer codes, have been used since the early 1970's to assist, but the data specification and sensor hardware design processes have been largely independent.

Traditionally, as illustrated on the left side of Figure 3, remote sensing mission planners evaluated user requirements and defined geophysical measurements and sensor specifications. The sensor specifications form the basis for the design required of the sensor contractor. Data requirements are decoupled from the sensor design, providing sensor designers with fixed design constraints. Data requirements may, however, include practical risk and cost implications unappreciated by the mission planner, possibly inconsistent with budget and risk priorities, or even with available sensor technology.

The NPOESS IPO sought to optimize remote sensing design and contracting by requiring sensor designers to both specify the data and design the sensor-algorithm system as indicated on the right side of Figure 3. This requires an integrated remote sensing system simulation capability. The government need only define and prioritize the geophysical measurements, and demand that the contractor define the system to meet those requirements within cost, data rate, mass, power, volume and schedule constraints.

By allowing tradeoffs between data quality and sensor-algorithm cost and risk, this approach also has the potential to maximize performance and minimize cost, schedule, and performance risk. These latter trades are not easily performed when the data specification process is decoupled from the hardware specification and design process. Allowing such interaction leads to a degree of system optimization not otherwise easily achievable.

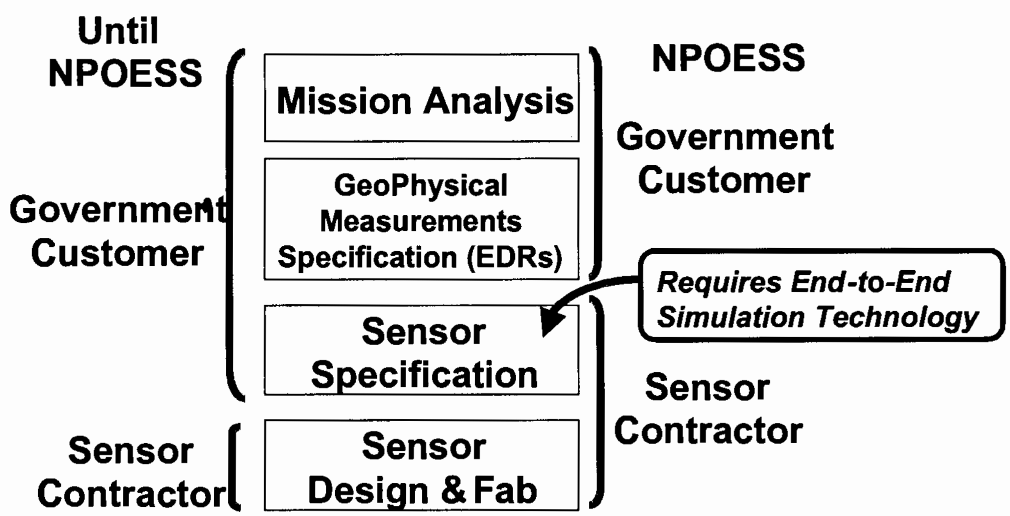

Fig. 3: The Specification and Design Process, Linked under NPOESS, Mandates the Sensor Contractor Provide a Robust End-to-end Simulation Testbed.

Because the requirements in the VIIRS SRD were couched in terms of geophysical specifications, Raytheon identified the construction of an end-to-end simulation testbed as critical to success. The testbed provided a quantitative link between sensor design and geophysical performance, and led to an excellent IPO system optimization rating by allowing the design team to trade geophysical measurement fidelity against the cost, performance, and risk of various sensor design options. The end-to-end simulation test bed, illustrated in the flow diagram of Figure 4, permitted parallel optimization of data and sensor specifications, as well as geophysical retrieval algorithm and sensor designs.

As indicated at the top left of Figure 4, ground truth test data sets (TDS) are converted into simulated Top-Of-Atmosphere (TOA) radiances. These serve as inputs to a sensor simulation (bottom right of Figure 4), which produces digital data representative of those anticipated from the sensor hardware. These digital data are converted to ground truth estimates using the remote sensing geophysical measurement retrieval algorithms that would be used on actual sensor data taken in orbit. Finally, the retrieved estimates are compared to the original ground truth as illustrated in the center of Figure 4.

Iterative changes to the sensor design and retrieval algorithms, as well as to the data requirements, allow the EDR quality to be improved while tracking sensor cost and risk to a selected level. Because the data character, the sensor design parameters, and the retrieval algorithms are all part of the same end-to-end simulation process, it is possible to conduct numerous complicated iterations on the system over a range of geophysical measurement requirements.

Raytheon's process incorporated the best available radiative transfer programs and geophysical measurement retrieval algorithms. The sensor simulation incorporated a combination of proven hardware simulation tools to tie the standard sensor design process into the end-to-end testbed. Most of the testbed development effort was expended in selecting the appropriate existing TDS and simulation modules, eliminating coding errors in the transfer of data from one module to another, and in data parameterization. Little original software was needed other than to implement algorithms to retrieve new geophysical parameters. In many cases, even those software modules could be drawn from proven libraries. Several geophysical requirements, however, required new retrieval algorithms based on published research[7,8]. The process illustrated in Figure 4 lends itself to relatively straightforward modification due to a modular architecture, and is therefore applicable, in principle, to any remote sensing system.

A key VIIRS design requirement was to compare the end-to-end system performance against the design costs and risks of developing the hardware and software needed to achieve various levels of performance, and to attempt to optimize cost, risk, and performance. Without the end-to-end simulation approach, or in a situation where the data requirements are contractually separated from the hardware design process as illustrated on the left of Figure 3, it is difficult to perform effective cost, risk, and performance tradeoffs.

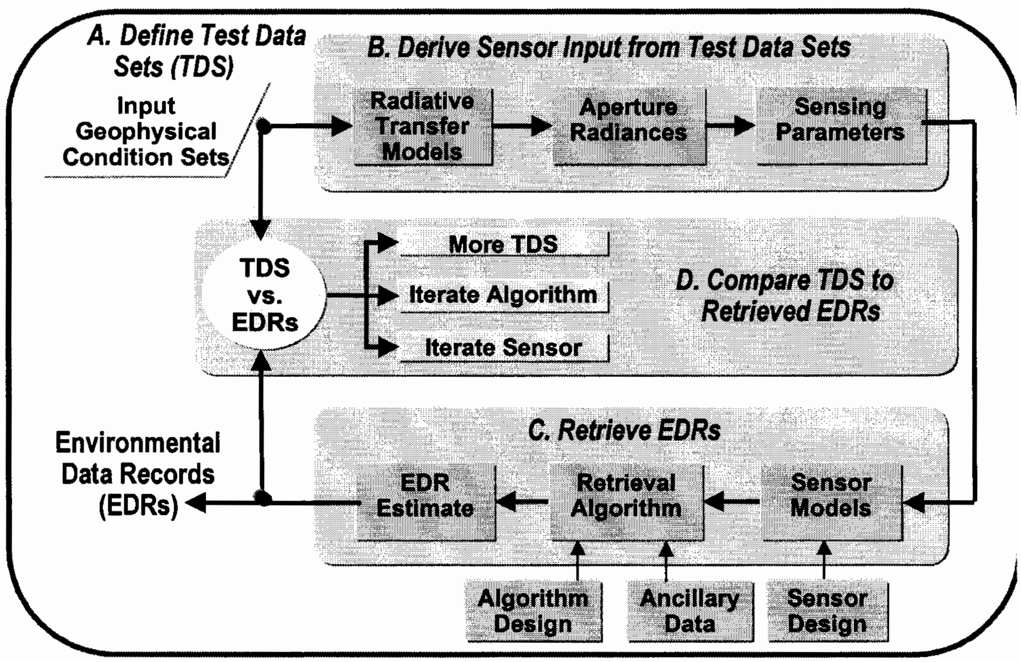

Fig. 4: End-to-end System Simulation, From Test Data Sets to Atmosphere, Sensor, and Retrieval Algorithms, Permits Step-by-step Insight and Inspection of Evolving Design Optimization.

The most fundamental sensor tradeoff is the scan approach, either pushbroom or cross-track ("whiskbroom") scan, as illustrated in Figure 5. Cooled shortwave infrared (SWIR) to longwave infrared (LWIR) spectral capability requires cross-track scanning to accommodate the 3000-km (112-degree) cross-track VIIRS swath with reasonable detector focal plane array (FPA) cooling requirements. A separate pushbroom or whiskbroom ocean color radiometer and Day/Night Band (DNB) imager could have been selected (as their FPAs operate near ambient temperature), but integral ocean color and DNB proved to offer Best-Value.

Integral ocean color spectral bands coregistered to the SWIR through LWIR bands provide significant benefits to Aerosol, Cloud, and Land Category IIA EDR performance[4]. This enables good ocean color performance in all orbits under favorable sun-angle conditions (typically less than 70 degrees solar zenith angle where sun-glint is absent). Ocean color operation in both morning and afternoon nominal orbits with a nadir-pointing sensor enables SRD-specified ocean color refresh in spite of sun-glint. Finally, integral ocean color is substantially less costly than a separate sensor.

Raytheon's initial Phase I VIIRS design concept incorporated a separate DNB sensor because the original cross-track whiskbroom scanner design employed a MODIS-like cross-track scan mirror that was incapable of collecting good reflectance band data in the terminator orbit when the sun is below the spacecraft. As illlustrated in Figure 6, our Phase I design efforts for the separate DNB design showed, however, that the multiple telescope design would be expensive. A significant design effort was undertaken to develop a scanner design that could integrate DNB to reduce cost and risk. Through multiple hardware design studies and demonstrations, Raytheon showed that a constant speed, 360-degree rotating telescope cross-track scanner overcomes the sun-impingement problem while improving DNB performance using low scatter optics required to service ocean color and other EDRs. This design solution provides sufficient sun-glare mitigation to offer >99.8 percent 3000-km swath DNB operability.

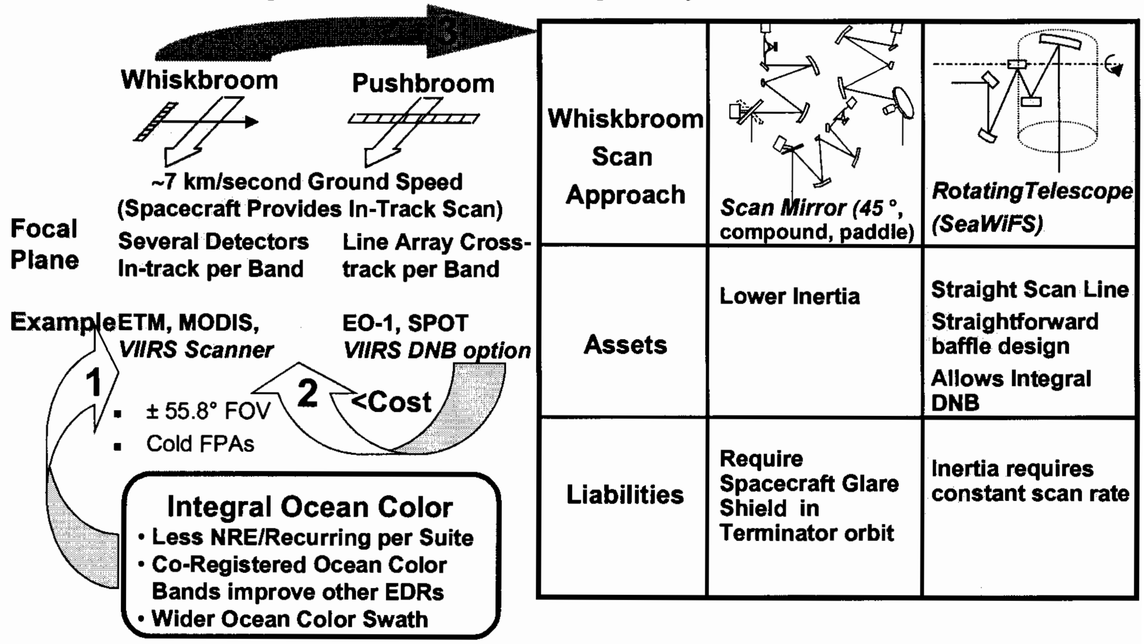

Fig. 5: Key Tradeoffs leading to Best Value single sensor VIIRS design.

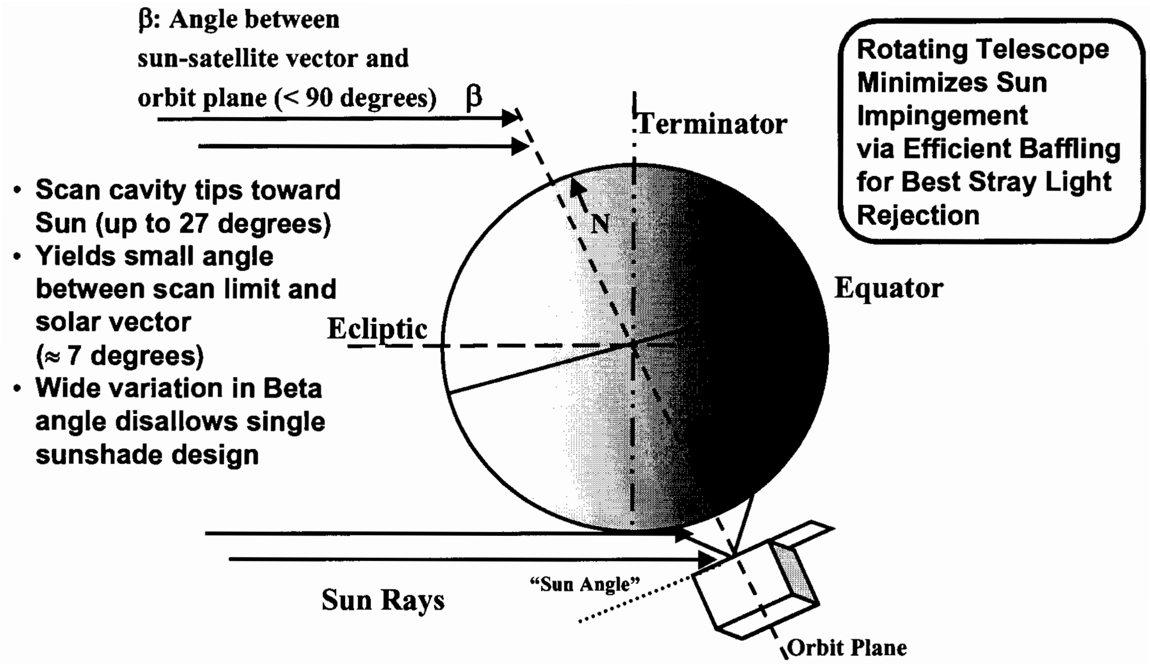

Fig. 6: Rotating Telescope was key to allowing Day/Night capability to be integrated into the scanner.

One important NPOESS requirement is to substantially improve on current operational performance by offering well calibrated and therefore scientifically more usable radiometry. This was underscored in the VIIRS SRD by the inclusion of both emissive and reflective radiometric calibration requirements. MODIS meets these requirements using an extensive suite of on-board calibration reference subsystems. A VIIRS cost as an independent variable (CAIV) trade showed that VIIRS SRD calibration requirements could be achieved at lowest cost and risk by retaining most MODIS calibration subsystems, illustrated in Figure 1.

A MODIS and Tropical Rainfall Measuring Mission (TRMM) Visible IR Scanner (VIRS) flight-proven "V-groove" blackbody is used to meet the emissive band calibration requirements of better than 1%. A combination of a MODIS and TRMM VIRS flight-proven Spectralon solar diffuser and MODIS flight-proven Solar Diffuser Stability Monitor (SDSM) together provide basic reflectance band calibration, backed by a space-view that includes occasional lunar views, as well. The rotating telescope design allows the calibration subsystems to be viewed once per scan, providing nearly continuous on-orbit blackbody emissive band calibration coefficient updates. Once per orbit solar diffuser calibration data are also obtained as VIIRS crosses over the poles in either a mid-morning or mid-afternoon equatorial crossing time orbit to obtain better than 2% accuracy reflective calibration performance. Solar diffuser reflectance band calibration is not available in the near-terminator orbit. As that orbit offers very few opportunities for substantially sun-illuminated scenes for which reflectance band data (other than the low-light imagery) are available, a significant reflectance band calibration accuracy relaxation is needed. A calibration of better than 5% in the terminator orbit is specified using cross-calibration from other orbits over the polar regions where other orbits cross the terminator orbit within the hour.

VIIRS spectral capability was optimized based on the IPO's priorities of Table 1. As illustrated in Figure 7, this capability is dramatically better than existing operational sensors, yet also represents a 40% simplification relative to MODIS. At the same time, however, the 22 bands comprise MODIS comparable spectroradiometry in the context of the VIIRS EDRs, because the reduction in spectral coverage primarily affects the MODIS sounding channels. Moreover, five of the 22 bands provide fine-resolution capability to address Imagery, the Normalized Difference Vegetation Index (NDVI), and Snow Cover EDRs. Therefore, VIIRS offers both MODIS-comparable spectro-radiometry and improved imaging capability compared to OLS, while the integrated single-sensor design allows coregistration of all bands, benefiting all the EDRs.

Furthermore, several sensor design drivers, including NDVI and snow cover as well as imagery require substantially finer horizontal sampling interval (HSI) than MODIS.

The Imagery EDR's horizontal spatial resolution (HSR) requirements were met with balanced optical and focal plane modulation transfer functions (MTFs). Thus, VIIRS meets the nadir and EOS Imagery HSR thresholds for imagery bands (for which the HSI matches the HSR at EOS) as shown in the lower portion of Figure 8. The detector field stops in the moderate resolution bands were sized to provide improved HSI for the coarser horizontal cell size (HCS) Category IIA EDR requirements, which also improves detector yield and lowers detector noise.

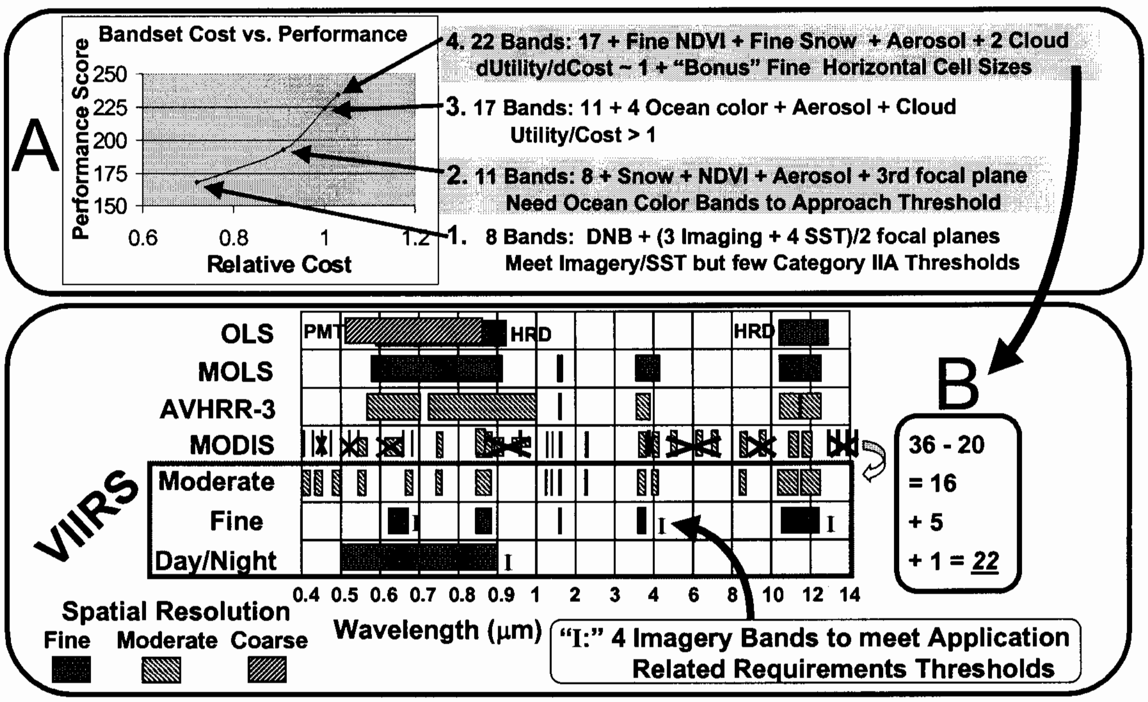

Fig. 7: VIIRS Spectral Bands were selected to optimize cost and performance.

Figure 8 shows the predicted spatial sampling as a function of scan angle from nadir to edge-of-scan (EOS). It is noteworthy that even with aggregation, the sensor offers HSI better than 1.3 km nearly to EOS in all bands. This is important because 1.3 km is required for many important EDRs, but only to 43.6 degrees off-nadir. Up to that point, the sensor offers both HSI and HSR better than the HCS requirements for those EDRs, including SST. As shown in Figure 8, better than 1.3 km HSI is provided well beyond 1700km, benefiting those EDRs with a 1.3 km HCS requirement up to 1700 km. VIIRS therefore offers nadir HSI significantly better than AVHRR and MODIS, and with better nadir signal-to-noise ratio (SNR) via 3:1 aggregation, as shown in Figure 9, following a patented conceptual approach[9]. At EOS, the HSI is 4:1 better in the cross-track dimension compared to AVHRR and MODIS, yet with comparable SNR improved over OLS. This enabled diverse DoD and Civil operational requirements to mutually support one another through an integrated single-sensor approach that balances improved imaging and spectroradiometry.

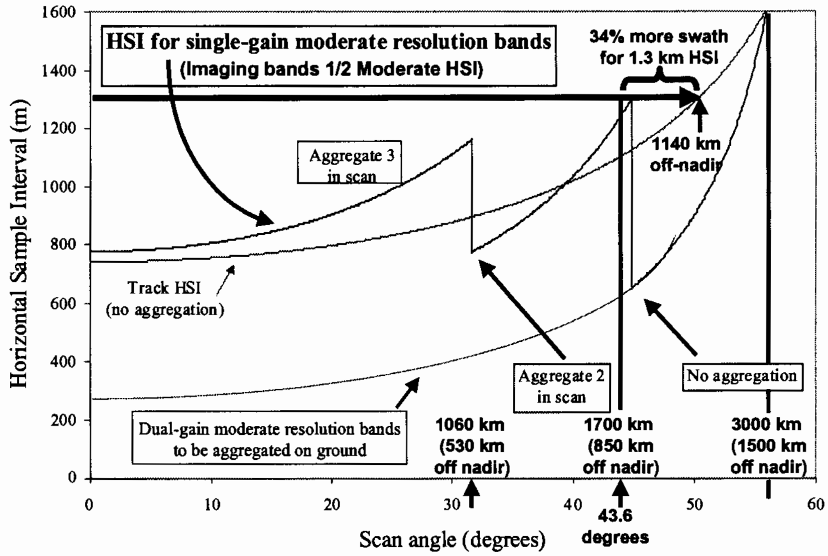

Fig. 8: Optimization of cross-track scan spatial sampling enables 2:1 HSI variation with excellent SNR.

MODIS, on Terra since December 1999 and launched on Aqua in May 2002, satisfies most of the VIIRS sensor performance requirements[7], except terminator orbit DNB sun-glare mitigation and imagery resolution. The VIIRS sensor design substantially improves on MODIS in other ways to improve EDR performance and lower cost and risk, while retaining MODIS science data continuity[8]. Specifically, as described below, key technology advancements allowed Raytheon to simplify the aft optics imaging and focal plane design to improve optical and focal plane spectro-radiometric performance compared to the MODIS design at lower cost and risk.

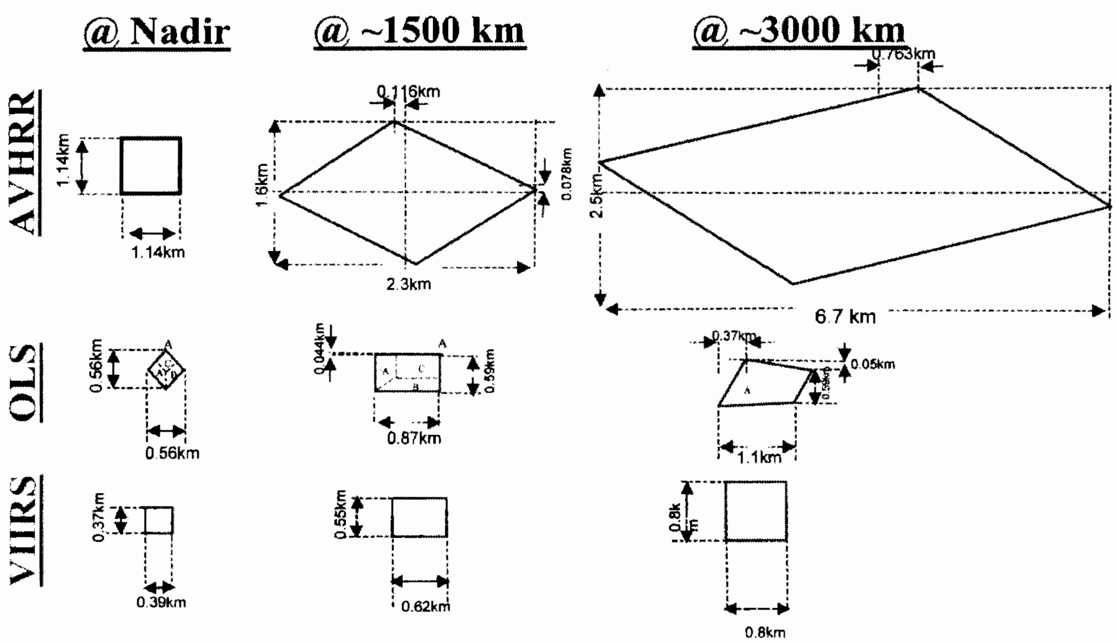

Fig. 9: VIIRS dramatically improves spatial resolution across the 3000 km swath compared to AVHRR (and MODIS, which is similar to AVHRR in this respect), approximately matching OLS imaging performance.

3. VIIRS DESIGN AND PERFORMANCE

As indicated in Figure 1, VIIRS is responsive to the IPO's requirements priorities outlined in Table 1. Flexibility to operate in all orbits without the spacecraft mounted solar glare obstructor (GLOB) currently used to shield the DMSP OLS from solar impingement, as well as near objective EDR performance, is provided. A key design element that enables these top priorities is a constant-speed rotating telescope cross-track scanner with image rotation compensating half angle mirror (HAM), proven over five years of SeaWiFS on-orbit operation.

This scanning design enables VIIRS to attain excellent night imaging solar rejection, even when the sun impinges into the aperture, as well as excellent stray-light rejection for ocean color imaging near clouds and coastlines. Advanced diamond-point turned (DPT) optical mirror surface machining enables the three-mirror anastigmat (TMA) 4x afocal telescope and a four-mirror anastigmat (FMA) imager to co-register the three focal planes indicated in Figure 2. This design provides an optical field-of-view (FOV) sufficient to allow space for the 22 spectral bands necessary to meet the EDR requirements.

Table 2 lists the sensor performance requirements and predicted performance, all derived by Raytheon based on the EDR flowdown process. The band center wavelengths and bandwidths, horizontal sample interval (HSI), signal-to-noise ratio (SNR) at typical radiance (generally very low) and maximum radiance, are given in the Table. Note that HSI is not the same as the horizontal spatial resolution (HSR), although for most spectral bands the two are very close in value. HSR is defined as half the inverse of the spatial frequency at which the modulation transfer function (MTF) equals 0.5. The VIIRS SRD specifies the imagery spectral band HSR, the only aspect of the sensor specified by the SRD beyond data rate, mass, power, and volume. HSRs for other spectral bands were specified by Raytheon based on the EDR horizontal cell sizes (HCS) specified in the SRD.

Table 2: VIIRS Requirements and CDR Predicted Performance by Spectral Band

		Band No.	Wave-length (μm)	Horiz Sample Interval (km Downtrack x Crosstrack)		Driving EDRs	Radi-ance Range	Ltyp or Ttyp	Signal to Noise Ratio (dimensionless) or NEΔT (Kelvins)		
				Nadir	End of Scan				Predicted	Required	Margin (%)
VIS/NIR FPA	Silicon PIN Diodes	M1	0.412	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	44.9	483	352	37%
						Aerosols	High	155	838	316	165%
		M2	0.445	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	40	560	380	47%
						Aerosols	High	146	847	409	107%
		M3	0.488	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	32	608	416	46%
						Aerosols	High	123	784	414	90%
		M4	0.555	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	21	544	362	50%
						Aerosols	High	90	643	315	104%
		I1	0.640	0.371 x 0.387	0.80 x 0.789	Imagery	Single	22	147	119	24%
		M5	0.672	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	10	366	242	51%
						Aerosols	High	68	511	360	42%
		M6	0.746	0.742 x 0.776	1.60 x 1.58	Atmospheric Corr'n	Single	9.6	318	199	60%
		I2	0.865	0.371 x 0.387	0.80 x 0.789	NDVI	Single	25	222	150	48%
		M7	0.865	0.742 x 0.259	1.60 x 1.58	Ocean Color	Low	6.4	490	215	130%
						Aerosols	High	33.4	487	340	43%
CCD		DNB	0.7	0.742 x 0.742	0.742 x 0.742	Imagery	Var.	6.70E-05	6.6	6	10%
S/MWIR	PV HgCdTe (HCT)	M8	1.24	0.742 x 0.776	1.60 x 1.58	Cloud Particle Size	Single	5.4	114	74	54%
		M9	1.378	0.742 x 0.776	1.60 x 1.58	Cirrus/Cloud Cover	Single	6	166	83	100%
		I3	1.61	0.371 x 0.387	0.80 x 0.789	Binary Snow Map	Single	7.3	76.4	6.0	1170%
		M10	1.61	0.742 x 0.776	1.60 x 1.58	Snow Fraction	Single	7.3	513	342	50%
		M11	2.25	0.742 x 0.776	1.60 x 1.58	Clouds	Single	0.12	15.2	10	52%
		I4	3.74	0.371 x 0.387	0.80 x 0.789	Imagery Clouds	Single	270 K	0.967	2.500	160%
		M12	3.70	0.742 x 0.776	1.60 x 1.58	SST	Single	270 K	0.224	0.396	77%
		M13	4.05	0.742 x 0.259	1.60 x 1.58	SST	Low	300 K	0.480	0.107	120%
						Fires	High	380 K	0.312	0.423	35%
LWIR	PV HCT	M14	8.55	0.742 x 0.776	1.60 x 1.58	Cloud Top Properties	Single	270 K	0.051	0.091	78%
		M15	10.763	0.742 x 0.776	1.60 x 1.58	SST	Single	300 K	0.030	0.070	130%
		I5	11.450	0.371 x 0.387	0.80 x 0.789	Cloud Imagery	Single	210 K	0.093	1.500	61%
		M16	12.013	0.742 x 0.776	1.60 x 1.58	SST	Single	300 K	0.054	0.072	34%

Table 2 also shows two radiance ranges in "dual-gain" bands. Each band's required radiance dynamic range was derived using the EDR flowdown process, and in seven bands the saturation radiance and SNR requirements at low radiance made it impossible to meet both the dynamic range and sensitivity requirements with a single detector gain setting. In these cases, we could have designed two separate detector arrays to meet the EDR requirements, one at high gain with excellent low radiance sensitivity, and another with lower gain and high saturation radiance. MODIS uses this approach for several spectral bands because at the time MODIS was designed, similar conflicting dynamic range and sensitivity requirements could not be met with one detector array. Since then, however, Raytheon developed a readout integrated circuit (ROIC) capacitive transimpedance amplifier (CTIA) individual detector unit-cell automatic gain control to cover the dynamic range with one detector array in a feature called "dual-gain." This allows the EDRs to be accommodated with seven fewer detector arrays than MODIS, reducing cost, data rate, and electronics mass, power, and volume.

Until VIIRS is launched, operational cloud analysts and scientists will continue to be restricted to either a pair of high-resolution bands (DMSP/OLS) or five (POES/AVHRR/3) moderate-resolution spectral bands. The imagery solution provided on VIIRS includes six high-resolution bands and an additional 16 moderate-resolution bands. One of these, a reflective panchromatic band, is operable in low-light conditions down to a quarter moon. Like the OLS, and unlike AVHRR, SeaWiFS, and MODIS, growth of the field of view from nadir to the edge of the 3,000 km swath (EOS) is held to a factor of two in the along-scan direction. Uncontrolled, due to a combination of slant-path range and Earth curvature, previous sensors had growths in a 1 km nadir observation to ~6 km at EOS as shown in Figure 9 above.

The 640, 3740, and 11450 nm bands, along with the day-night pan band fully achieve the SRD imagery requirements for manually-generated cloud detection and typing. Synergistic addition of the 865 and 1610 nm imagery bands and 16 other high signal-to-noise, moderate spatial resolution spectral bands, satisfies many objective-level requirements. These ancillary "helper bands," such as the 1378 nm cirrus detection band, provide a significant amount of new analysis information that transfers MODIS technology[10] into the operational environment as illustrated in Figure 10. It will be important to train the users so that the full multispectral value of VIIRS is realized.

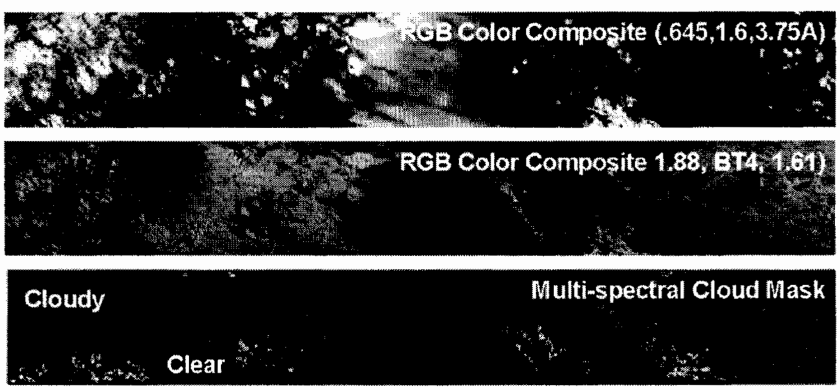

Fig. 10: All 22 VIIRS bands can be used together to produce a greatly improved cloud and sea-ice operational detection and characterization capability.

The predicted SNR for all bands nadir to EOS for both single and dual-gain bands have margin of better than 40% for most cases against the performance requirements listed in Table 2. The VIIRS optical design is shown in Figures 11 and 12, a Pro-Engineer rendering and an optical schematic illustrating the layout and operation, respectively. The rotating telescope comprises an afocal three-mirror anastigmat (TMA) producing a collimated exit beam one-quarter the diameter of the entrance beam. The output of the rotating TMA is directed to a flat mirror rotating around the same axis as the telescope in the same direction, but at half the speed, called a half-angle-mirror (HAM). The DNB/VNIR focal plane is at the upper right of the FMA module, and the SWIR/MWIR and LWIR FPAs are in the dewar module on the upper left of the